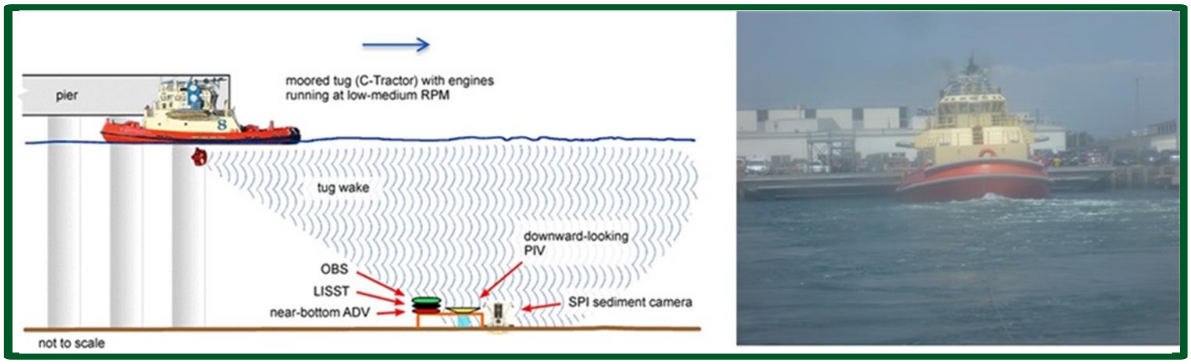
ESTCP
Cost and Performance Report

(ER-201031)



Evaluation of Resuspension from Propeller Wash in DoD Harbors

May 2016

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ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 05-01-2016

2. REPORT TYPE Cost & Performance Report

3. DATES COVERED *(From - To)* 4/01/2010 - 04/30/2016

4. TITLE AND SUBTITLE

Evaluation of Resuspension from Propeller Wash in DoD Harbors

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER ER-201031

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

SERDP and ESTCP Office
4800 Mark Center Drive, Suite 17D08
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

ESTCP

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

A study was conducted to evaluate impacts of resuspension from propeller wash in DoD harbors. This study included both field data measurement and calibration of numerical models. The study included three linked, yet separate studies, including resuspension potential by tug wash, fate and transport, and re-migration, re-deposition and re-contamination potential of the sediment plumes from tug wash. Model-data comparisons were conducted for both the erosion potential model (Graphic Maynord's model) and the fate and transport model (CH3D) for San Diego Bay, CA. The calibrated models were then used to evaluate propeller wash impact in Pearl Harbor, HI, and Sinclair Inlet, WA. Study results demonstrated that, in spite of the complexities associated with the transport and dynamics of propeller-wash induced sediment resuspension, study tools, including both key field data and adequately calibrated models, were effectively developed and applied to describe and predict key processes and impacts associated with propeller wash in DoD harbors.

15. SUBJECT TERMS

Propeller Wash, Contaminated Sediment, Tugboat, Models, Fate and Transport, CH3D, Maynord's Model, FANS, Metal Partitioning

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	U	52	Pei-Fang Wang
					19b. TELEPHONE NUMBER *(include area code)* 619-553-9192

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocimeter
CH3D	Curvilinear Hydrodynamics in three dimensions
CoC(s)	Contaminant(s) of Concern
DD3	Drydock 3
DD6	Drydock 6
DDG	Guided Missile Destroyer
DoD	Department of Defense
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
FANS	Finite Analytical Navier-Stokes Solver
IMF	Intermediate maintenance Facility
$Kg/m^2/sec$	Kilogram-meter per second
OBS	Optical Backscatter Sensor
PIV	Particle Image Velocimeter
PSNS	Puget Sound Naval Shipyard
RPM	Revolutions per minute
SPI	Sediment Profiling Imagery
SSC	Suspended Sediment Concentrations
TICKET	Tableau Input Coupled Kinetic Equilibrium Transport
TSS	Total Suspended Solids
USS	United States Ship
V	Velocity

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ACKNOWLEDGEMENTS

Contributions from a team of dedicated experts are acknowledged. First and foremost, the authors would like to thank the ESTCP program office (manager: Dr. Andrea Leeson) and the technical committee (Mr. Tim Thompson) for the funding and technical guidance during the study. Field study in San Diego Bay would not have been possible without the strong support of the Commander Navy Region Southwest (CNRSW), including Mr. Brian Gordon (manager), Mr. Paul Patricio (Port Ops Waterfront PM and Portmaster) and the crew of C-Tractor 14 tugboat. Equal appreciation goes to Ms. Kimberly Markillie (manager of NAVFAC-HI), who provided the logistic support for the field study in Pearl Harbor. On-site support for the sediment trap study in Pier 7 of Sinclair Inlet, WA, from Dr. Bob Johnston (SSC PAC) and the Puget Sound Naval Shipyard is appreciated.

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EXECUTIVE SUMMARY

Propeller wash disturbs bed sediment in Department of Defense (DoD) harbors, a phenomenon constantly observed and occasionally reported. While these resuspension events occur frequently, their potential effects on erosion, transport, re-deposition, and re-contamination of bottom sediments have not been rigorously studied or quantified. This study aims to demonstrate and validate an innovative quantitative method that integrates predictive models with information from state of the science measuring devices/tools used to determine critical parameters that govern propeller wash resuspension and subsequent fate and transport of re-suspended sediments in DoD harbors. This approach will provide the means for prediction of the stability of remediation systems under hydrodynamic conditions prevailing in DoD harbors. Furthermore, this approach can guide the design of sustainable sediment structures (caps) that can prevail under such hydrodynamic conditions. Benefits of the study include: (1) improved understanding of resuspension by propeller wash and its impact on sediments in DoD harbors; (2) predictive capabilities for potential re-contamination of sediment remedial sites; and (3) information-based decision tools for managing propeller wash-induced sediment resuspension, transport and re-contamination potential.

OBJECTIVES OF THE DEMONSTRATION

Objectives of the study included: 1) demonstrate and validate innovative methods to estimate erosion potential by propeller wash in two DoD harbors (source term); and 2) characterize, map and predict fate and transport of sediment plumes and contamination by propeller wash (fate and transport).

TECHNOLOGY DESCRIPTION

To achieve the first objective, we have conducted both laboratory and field studies to measure the parameters that govern propeller wash and its erosion potential, and then refined and validated the Graphic Maynord's (1984) model for evaluation of erosion potential. For the second objective, we have conducted field studies to measure masses of different sediment particle sizes and the associated metal loading, in propeller wash plumes in San Diego Bay, and Pearl Harbor, and have deployed sediment traps and measured sediment depositions at Pier 7 in Sinclair Inlet. The linked CH3D+TICKET was successfully implemented and validated for simulation of fate/transport and re-deposition of the sediment plumes from propeller wash in San Diego Bay.

A fortuitous event resulted in validation of the FANS model for prediction of sediment resuspension by a deep draft vessel. While working on the resuspension event in Bravo Pier, Pearl Harbor, information on sediment resuspended during the transit of the USS Chafee from Bravo Pier led to the application of the FANS model for that specific case. The FANS model successfully predicted the plume patterns observed during the transit of the deep-drafted vessel.

DEMONSTRATION RESULTS

In general, all quantitative performance objectives were successfully met. The water velocity produced by the propeller thrust, and the associated shear stress was successfully estimated for 92% of the data and all four propeller speeds. The erosion rate produced was successfully estimated for 7 out of 9 data sets. Those two data sets that were not estimated were measured after the propeller stopped.

Resuspended sediment load was successfully predicted for 89% of the measured data, and metal load was predicted correctly for 86% of the dissolved copper data, and 81% of the total (dissolved and particulate) copper data. Copper partitioning estimated with the CH3D+TICKET model was correctly estimated in 23 of the 24 field data sets, or 96% of the time. Copper loads in sand, silt and clay were successfully predicted for 83% of the data.

Similarly, qualitative objectives were successfully met. As evidenced from the quantitative objectives results, linking CH3D with TICKET was successfully accomplished, providing data that met quantitative objectives. Also, application of CH3D to estimate loads of total suspended solids was successful for the Pearl Harbor demonstrations. FANS correctly predicted the resuspension of bottom sediments by the USS Chafee, which was measured incidentally during the demonstration in Pearl Harbor.

IMPLEMENTATION ISSUES

Implementation of the developed models to other harbors must include calibration of the models. Background information on boundary conditions, bathymetry, tides, winds, and currents are required to calibrate hydrodynamic fate and transport models. Background information on the size-class distribution of particles in sediments in the harbor of interest, as well as the associated load of contaminants is required for calibration and validation of the models. Performing a controlled resuspension event, similar to the ones performed in San Diego Bay and Pearl Harbor, will provide the critical parameters for calibration. Collection of these field data is costly and laborious, but important for improving the confidence on the results. Maynord’s model is not appropriate for those cases when the ratio of propeller diameter to propeller-to-bottom distance is greater than 1.2 (shallow depths, or small distance between hull and bottom).

These developed models should provide the capability for designing sediment remediation structures able to withstand effects from propeller wash. Once models are calibrated and validated, they will provide information on the maximal ship speed that the sediment remediation system can withstand before resuspension initiates, allowing for designation of speed zones. This information will also allow designing sediment remediation structures robust enough (might not be cohesive) to withstand ship transit in the area of interest. Such structures should survive long enough to provide the maximal remedial effect (i.e., the best return of investment).

Cost for model implementation in another harbor will fluctuate depending on the background information already available, and the degree of precision required for the predictions. A full approach implementation is estimated to be in the order of $400K US dollars. When considering that the cost for sediment remediation for the DoD is estimated in about $2B US dollars, then the application of the tools developed here should warrant the best return for the investment for sediment remediation.

1.0 INTRODUCTION

Field studies were conducted to measure and characterize water velocities, propeller generated turbulence field and four size-classes (i.e., sand, silt, clay and dissolved) of particles in a plume of sediment re-suspended by propeller wash to determine sediment resuspension loads, and fate and transport of particles and associated contaminants of concern (CoCs). This data was used for simulation and evaluation of resuspension potential for a tugboat with the Maynord's model (Maynord, 1984) and for a Guided Missile Destroyer (DDG) with the Finite Analytical Navier-Stokes Solver (FANS model (Chen et al., 2003). The information from these models was then fed to a combination [i.e., linked Curvilinear Hydrodynamics in three dimensions plus Tableau Input Coupled Kinetic Equilibrium Transport (CH3D+TICKET)] of the fate and transport model CH3D (CH3D; Wang et al., 2000; 2007) with the TICKET model (Farley et al., 2008, 2011) for simulation of distribution of redeposited sediments and associated CoCs. The linked CH3D+TICKET was successfully calibrated for San Diego Bay, CA.

1.1 BACKGROUND

Over the past decade, we have witnessed significant effort taken in remediation of contaminated sediments with remedial actions that include, dredging, active or passive capping and natural recovery. However, as discussed in the Strategic Environmental Research and Development Program and Environmental Security Technology Certification Program (ESTCP) Workshop Report on *Research and Development Needs for Long-Term Management of Contaminated Sediments* (October 2012), there is a lack of understanding on how effective these remedial efforts are in both the short and long term.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objectives of the study include 1) demonstrate and validate innovative methods to estimate erosion potential by propeller wash in two Department of Defense (DoD) harbors (source term), and 2) predict fate, transport, and CoC partitioning in sediment plumes from propeller wash (fate and transport).

1.3 REGULATORY DRIVERS

Regulation of contaminated sediments is usually co-located with contamination issues in the water column. Under the Federal Clean Water Act, Section 303(d), states are required to identify all water bodies that do not meet water quality standards, this will trigger other actions that could identify co-located sediment contamination. Similarly, identified impaired water bodies are included in the 303(d) list, and remedial strategies, water cleanup plans, or total maximum daily loads must be developed to bring the water body back into compliance, which will include sediment characteristics/contamination. Once the sediments are characterized as contaminated, then the Comprehensive Environmental Response, Compensation, and Liability Act , which makes federal agencies liable for releases of hazardous material (contaminated sediments), will require them to take short-term removal of the material and/or long-term remedial actions.

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2.0 TECHNOLOGY

This study aims to demonstrate and validate an innovative quantitative method that integrates predictive models with information from state of the science measuring devices/tools for critical parameters that govern propeller wash resuspension and subsequent fate and transport in DoD harbors.

2.1 TECHNOLOGY DESCRIPTION

The overall framework and components of the study are shown in Figure 2-1. First, measuring devices were calibrated and validated in the laboratory prior to deployment. In the field, water velocities and the turbulence field produced by a tugboat propeller, and subsequent resuspension of sediment were measured to determine the physical conditions that produce resuspension. The field/laboratory techniques that fed input into the models are shown in Table 2-1.

In San Diego Bay, measurements of the tug wash resuspension potential were used to calculate bottom shear in order to calibrate the Maynord model against measured velocities, bottom shear, and total erosion rate. The fate/transport study for San Diego Bay, the calibrated Maynord's model was then used to predict sediment and contaminant mass re-suspended by the propeller wash from a tugboat under a controlled propeller running environment. Model-predicted sediment and contaminant mass from the tugboat were used as input to CH3D+TICKET to predict sediment fate and transport. Predicted water column sediment and metal concentrations were compared with the field data measured at 17 stations in the vicinity of the pier region during the two hour period following the resuspension event. The field/laboratory techniques that feed input into the models are shown in Table 2-1.

In Pearl Harbor at Bravo and Oscar Piers, pump sample data were used as input to CH3D to predict fate and transport of sediments and associated contaminants. Maynord's model was not used because the model had been calibrated for a larger tug in San Diego and was not felt appropriate to Pearl Harbor conditions. In Pearl Harbor, the re-suspended sediment acoustically detected behind a deep draft vessel was used to validate sediment resuspension predicted by the FANS model. Finally, the sediment caught in traps from the three deployments in Sinclair Inlet during January to June, 2014 was compared with model-predicted footprint from potential resuspension events near the site. Based on measured data and model results, analyses were conducted on the potential sources of resuspension/deposition scenarios.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Modeling, coupled with calibrating/validating field measurements is the typical approach used to estimate dispersal in the water column. The main cost is the model set up, requiring data on initial conditions, and a model tuned to site-specific conditions. The main benefit is broad applicability if the model is validated. The U. S. Army Corps of Engineers has been active in measuring and modeling transport of sediment, developing Maynord's model in 1984. They have also used CH3D, coupled with the US Environmental Protection Agency nutrient model WASP for eutrophication studies in non-DoD harbors. This study is unique as far as we know in combining Maynord's model, CH3D, and TICKET to predict the source, fate and transport, and partitioning of re-suspended sediments and contaminants in Navy harbors.

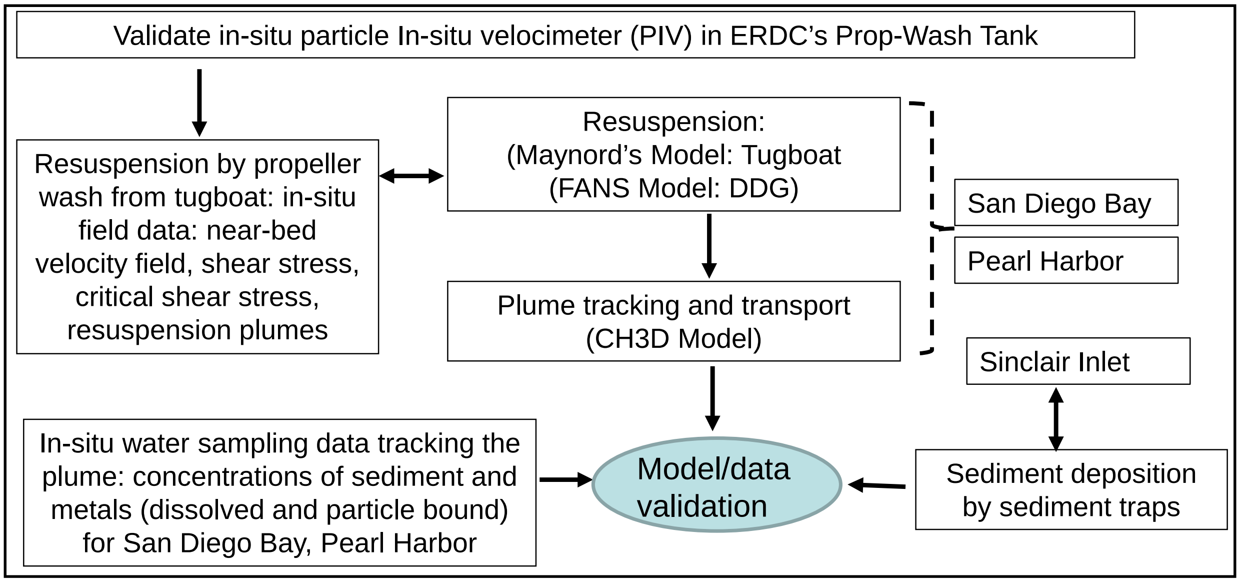

Figure 2-1. Study Framework and Components Including Both Laboratory Study, Field Work and Modeling Studies.

Table 2-1. Field and Model Efforts Used in the Sediment Resuspension and Transport Study.

Task	Site and Date	Field/Laboratory Gear	Model(s)
(1) Wake velocity field	San Diego Dec 2012	ADV	Maynord
(2) Critical shear stress	San Diego Mar 2012	ADV PIV	Maynord
(3) Resuspension and transport	San Diego Jul 2012	OBS Sediment sieves ICP-MS	Maynord CH3D
(3) Resuspension and transport	Bravo Pier, Pearl Harbor, Aug 2012	OBS ADCP SPI Sediment sieves ICP-MS	CH3D
(3) Resuspension and transport	Oscar Pier, Pearl Harbor, Aug 2012	OBS ADCP SPI Sediment sieves ICP-MS	CH3D
(4) Resuspension by deep draft vessel	Bravo Pier, Pearl Harbor, Aug 2012	ADCP	FANS
(5) Resuspension and transport	Sinclair Inlet, Jan-Jun 2014	sediment traps sediment sieves ICP-MS	Maynord CH3D

ADV= Acoustic Doppler Velocimeter, PIV= Particle Image Velocimeter, OBS= Optical Backscatter Sensor, ICP-MS= P-Mass Spectrometry, ADCP= Acoustic Doppler Current Profiler, SPI= Sediment Profiling Imagery.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for this effort are based on the precision in estimating the magnitude of the critical parameters and contaminant load associated with resuspension of sediments by propeller wash. As shown in Table 3-1, there are quantitative objectives for the precision of estimating the water velocity and shear stress that produces the resuspension of bottom sediments. There also are quantitative objectives on the precision of estimating the mass or re-suspended sediments and contaminant load resulting from the propeller wash effect. Finally, there also are quantitative objectives in estimating the partitioning of metals (i.e., copper) between re-suspended particles and the surrounding water.

Qualitative objectives are related to the success in linking CH3D and TICKET for estimating the partition of metals between suspended particles and water, and the estimation of total particle load [i.e., total suspended solids, (TSS)] from propeller wash event.

In general, all the quantitative performance objectives were successfully met. The water velocity produced by the propeller thrust, and the associated shear stress was successfully estimated for 92% of the data and all four propeller speeds. The erosion rate produced was successfully estimated for 7 out of 9 data sets. The data sets that were not estimated were measured after the propeller stopped. Re-suspended sediment load was successfully predicted for 89% of the measured data, metal load was predicted correctly for 86% of the dissolved copper data, and 81% of the total copper data. Copper partitioning, estimated with the CH3D+TICKET model, was correctly estimated in 23 of the 24 field data sets, or 96% of the time. The objective for estimation of copper loads in sand, silt, and clay was successfully met for 83% of the data.

Similarly, the qualitative objectives were successfully met. As evidenced from the quantitative objectives results, the linking of CH3D with TICKET was successfully accomplished, providing data that met quantitative objectives. Also, the application of CH3D to estimate loads of TSS was successful for the Pearl Harbor demonstrations. In that demonstration, the FANS's model correctly predicted the resuspension of bottom sediments by the United States Ship (USS) Chafee, which was measured incidentally during the demonstration in Pearl Harbor.

Table 3-1. Performance Objectives.

Performance Objectives	Metric	Data/Model Requirements	Success Criteria	Results
Quantitative Objectives				
Sediment resuspension model for tugboat	Calibrated resuspension model for San Diego Bay	Accuracy comparison of measured velocity (V) by PIV and ADV (field data)	Difference of mean (V_{piv}-V_{adv}) <5 cm/s or <50%	Criteria met for over 92% of data
		Velocity field by Maynord's model for four prop speeds	Mean velocity (model-data) <10 cm/s or < 50%	Criteria met for all four prop speeds
		Bottom shear stress (cumulative)	Mean (model-data) <0.1 Pa-Hr, or <50 %	Criteria met for all four prop speeds during the 35-min test
		Erosion rate (cumulative)	Measured-calculated cumulative erosion <0. 2 mm or <50%	Criteria met for 7 out of 9 data points, no corresponding model results for the other two field data, which were measured after prop stopped running
Fate and transport model of size-specific re-suspended sediments	Calibrated and validated sediment fate and transport model for San Diego Bay	Water column sediment concentrations and grain size	Difference (model-data) of water column sediment concentrations <0.5 mg/L or < 50 %	Criteria met for 89% of the data points for clay, silt and sand in the vicinity of the pier
		Water column dissolved and total copper concentrations	Difference (model-data) of water column dissolved and total copper <3.1 µg/L or <100 %	Criteria met over 86% of the data for dissolved copper, and over 81% of the data for total copper
Linked CH3D+TICKET Model	Calibrated and validated contaminant partitioning model for San Diego Bay	Partitioning coefficient for copper between field data and look-up table	Difference (field data-estimated) of copper partitioning <0.1 or <75%	Criteria met for 23 out of 24 field data sets
		Water column particulate copper concentrations	Difference (model-data) of water column copper concentrations bound by clay, silt and sand <3.1 µg/L or <100 %	Criteria met over 83% of the data points including copper concentrations bound by clay, silt and sand
Qualitative Objectives				
Linked CH3D+TICKET Model	Models linked	Compatible model input and output files	Models linked	Linked CH3D+TICKET completed with look-up table derived from field data
Fate and transport model for Pearl Harbor	CH3D application for fate and transport for Pearl Harbor	TSS data tracking the bulk of the plumes	Model-simulated TSS concentrations compared with TSS, qualitatively	Model and data consistent in transport patterns
		Tracking (incidental) bow wake of USS Chafee	Incidental tracking and measured TSS plume in the wake of USS Chafee (deep draft), as predicted by FANS model	Sediment plumes from deep-draft USS Chafee predicted by the FANS model and measured by ADCP

4.0 SITE DESCRIPTION

4.1 SITE LOCATION AND CHARACTERISTICS

San Diego Bay. San Diego Bay is a natural harbor with deep water port located in San Diego County, California near the US–Mexico border. The bay is 12 miles (19 km) long and 1 to 3 miles (1.6 to 4.8 km) wide. Most of the piers for naval vessels are located at Naval Station San Diego along the north-east coast in the middle section of the bay. Docking, berthing, and tugging of naval vessels within the naval piers are routine activities, which result in resuspension of bottom sediments and sorbed contaminants. Tugging and docking activities are believed to be responsible for a major portion of bottom sediment resuspension in the region of Naval Station San Diego as well as in San Diego Bay in general (Wang et al., 2004). Pier 4-5, where the majority of docking activities take place, is chosen to be the first test site (Figure 4-1).

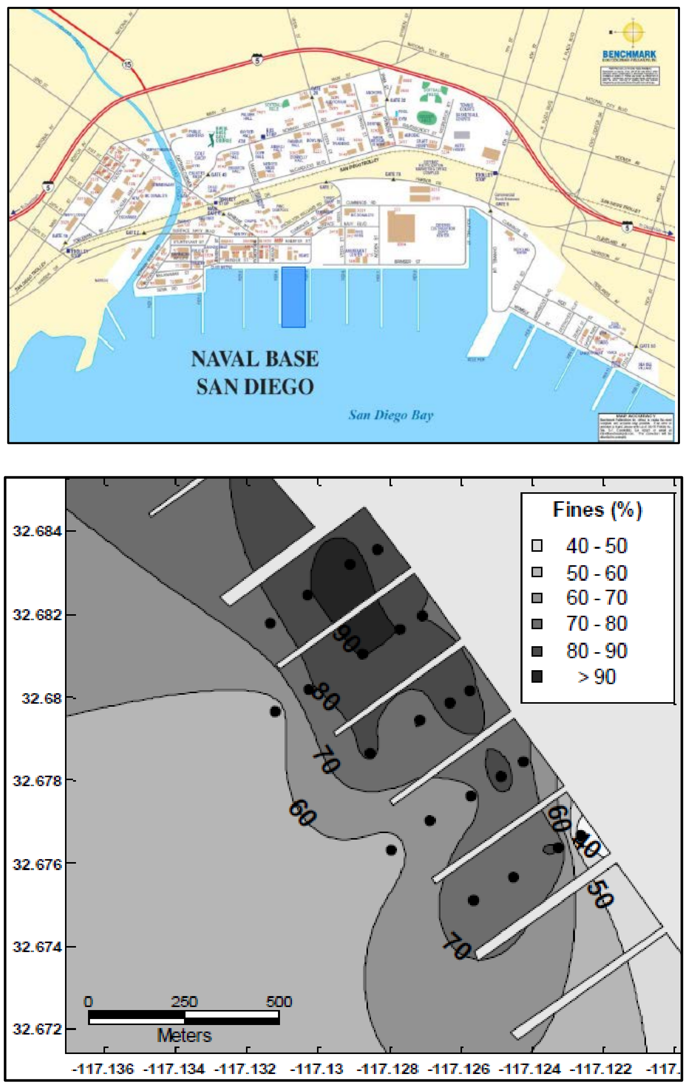

Figure 4-1. Map of the Study Site (Blue Box) in Naval Base San Diego, San Diego Bay, on Top, and Distribution of Fine Sediments in the Area of Study in the Bottom.

Pearl Harbor. Pearl Harbor is located on the island of Oahu and has been a homeport to the United States Navy Pacific Fleet for nearly 100 years. Naval Station Pearl Harbor is homeport to 29 Navy ships. The harbor has an entrance at the south and is fan-shaped with four sub-basins: West Loch, Middle Loch, East Loch, and Southeast Loch (Figure 4-2). A navigation channel extends from the entrance 7.6 km (4.7 miles) northward to the northern boundary of East Loch. The distance of the west-to-east boundaries of the harbor is approximately 8.6 km (5.3 miles). The harbor has a total surface area of 19.3 km^2 (7.5 $mile^2$), and an average depth of 9.2 meters (30.2 feet). Evans et al. (1974) were the first to report on the general flow and transport patterns in Pearl Harbor based on the analysis of the data measured during a 1-year period starting in June 1972. Sediment resuspension and redistribution by propeller wash was also analyzed by Wang et. al., (2009a).

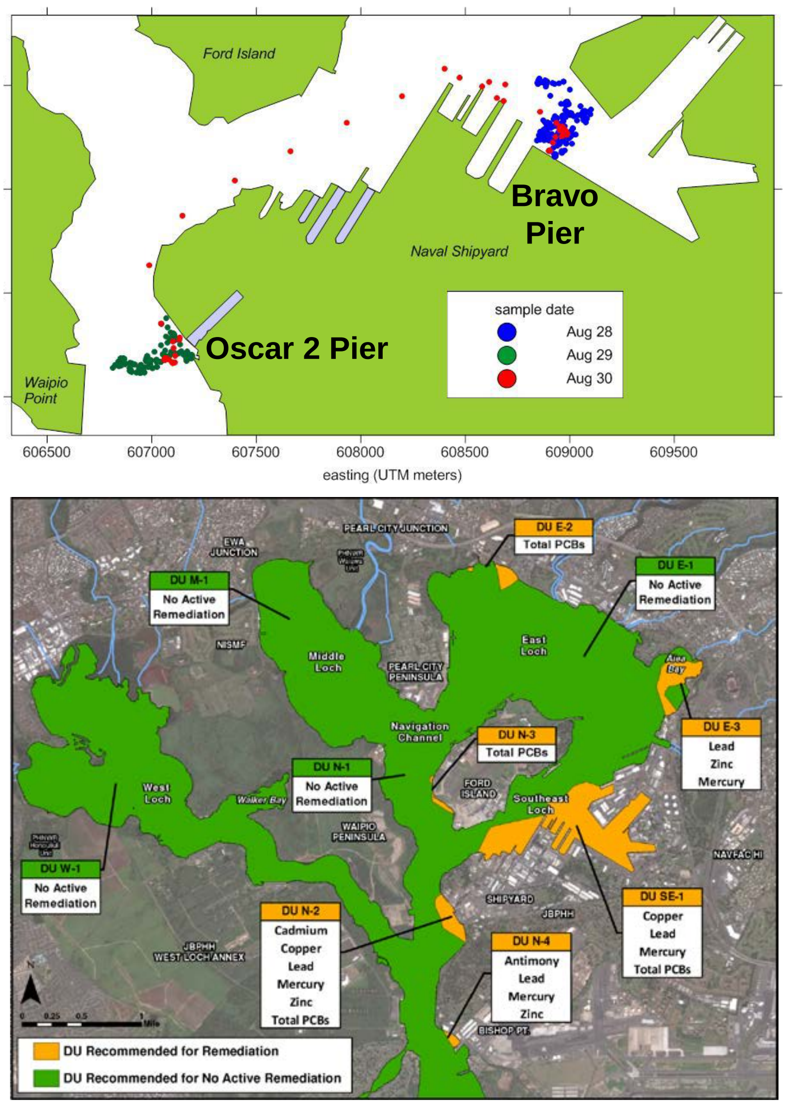

Figure 4-2. Map of the Study Site in Pearl Harbor Naval Shipyard & Intermediate Maintenance Facility, Pearl Harbor, on Top. And Distribution of Contaminants of Concern in Sediments in the Area of Study in the Bottom.

Sinclair Inlet. Puget Sound Naval Shipyard (PSNS) was established in 1891 on Sinclair Inlet as a Naval Station and was designated Navy Yard Puget Sound in 1901. Following World War II, Navy Yard Puget Sound was designated PSNS. The most prominent fluctuations in sea level and currents in Sinclair Inlet (Figure 4-3) are caused by tides. A demonstration project is underway at Pier 7, PSNS, and Intermediate Maintenance Facility (IMF) in Bremerton, Washington, under ESTCP project ER-201131. It is being conducted to demonstrate and validate placement, stability, and performance of reactive amendments for the treatment of contaminated sediments in an area with elevated polychlorinated biphenyl and Hg contamination.

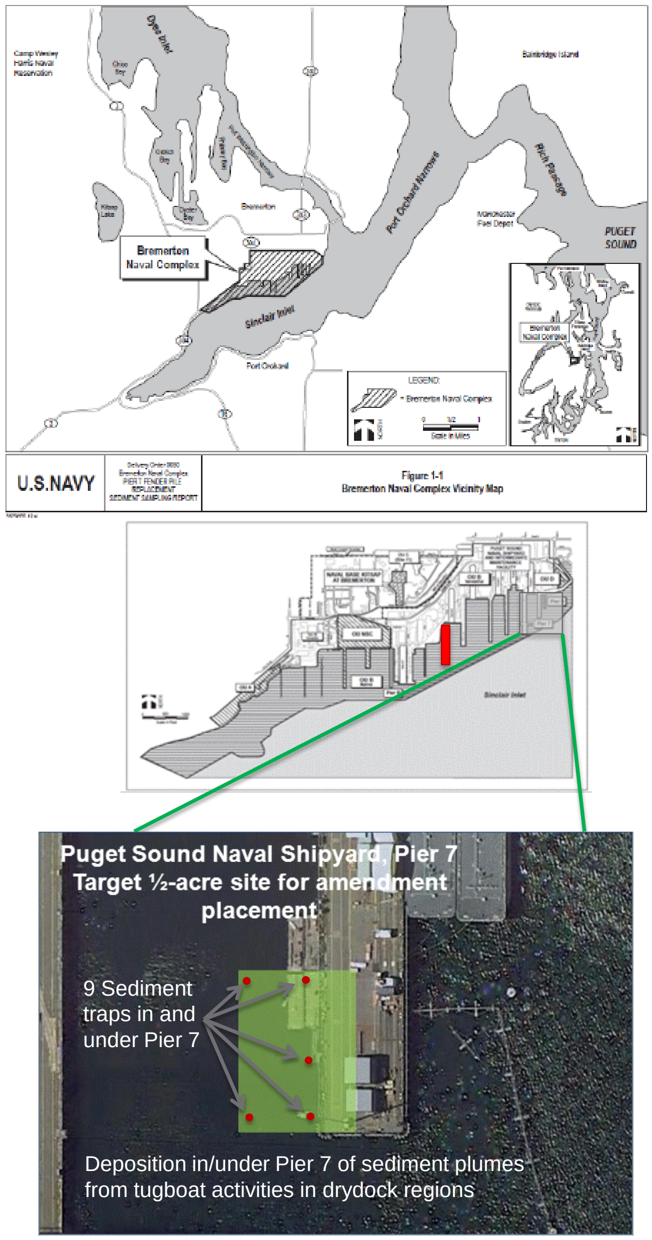

Figure 4-3. Map of the Study Site in Bremerton Naval Complex, Sinclair Inlet, Top Two Figures. And Picture of the Remediation Site under Pier 7 at the Bottom.

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5.0 TEST DESIGN

The overall framework and components of the study is shown in Figure 2-1 above. Following we provide a short description of the approach.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

Three DoD harbors were studied, San Diego Bay, Pearl Harbor, and Sinclair Inlet. The experimental approach for each was somewhat different. The critical parameters and development of the Maynord's, CH3D, and CH3D+TICKET models, with calibration and validation was initially done in San Diego Bay (Figure 5-1). These models were then implemented for Pearl Harbor, where the FANS model was validated for prediction of resuspension by deep draft ships (Figure 5-1). The final effort in Sinclair Inlet was on the application of the Maynord's and CH3D models for prediction of recontamination of a remediation site in that area (Figure 5-1).

5.2 RESUSPENSION CHARACTERIZATION

Three propeller wash resuspension events were undertaken in this study, one in San Diego and two in Pearl Harbor. The first resuspension event took place on 4 April 2012 in San Diego Bay, while the other two events were conducted 28 August (Bravo Pier) and 29 August 2012 (Oscar Pier) in Pearl Harbor. Data from these field studies were used to compare and validate the propeller resuspension potential model and the fate and transport model.

Background samples of sediment and water were collected prior to any resuspension event. A C14 Tractor and a slightly smaller Tiger tug boats were used in San Diego Bay and Pearl Harbor. A diagram of the resuspension event procedure, including a schematic of the mapping is shown in Figure 5-2. The suite of instruments used to characterize the resuspension potential is shown in Figure 6-1, and was used in the three resuspension events.

Table 5-1 lists the types of background and plume samples that were collected for all three resuspension studies. The samples were sub-sampled in our laboratory facilities following the same procedure for each carboy. A flow chart of the analysis of CoCs (i.e., metals and organic contaminants) is shown in Figure 5-3. Where the green boxes represent the CoCs concentration measured in the filtered seawater sample with particles for each size-fraction. Concentrations for each fraction (green boxes) were determined by subtracting the concentration derived from the next finer filter. The mass of particles retained by the 60-µm mesh (sand), 5.0-µm (silt), and 0.4-µm (clay) filters (brown boxes), is quantified as dry weight by the difference between tare and dry weight. For practicality, the original water sample collected in the field may be sub-sampled to allow parallel filtrations for CoC concentrations and particle mass. Only total and dissolved CoCs are determined for the background water concentrations.

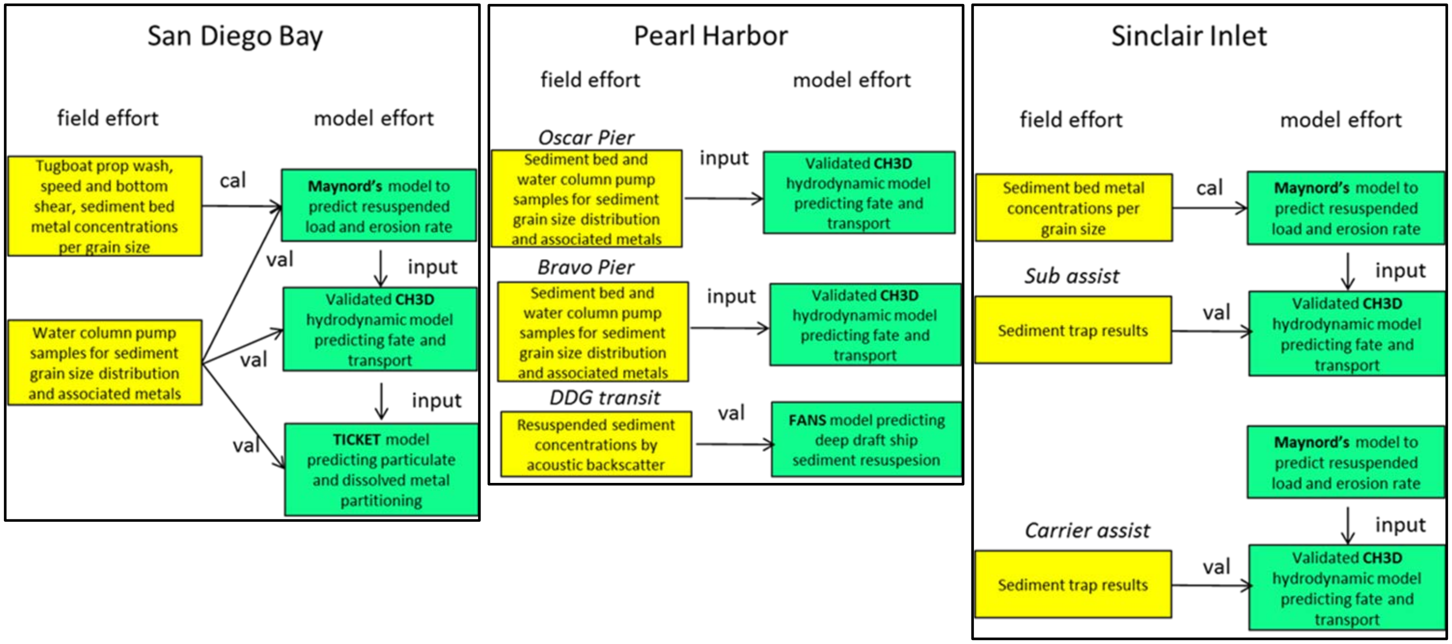

Figure 5-1. Conceptual Description of the Field and Model Efforts in San Diego Bay, Pearl Harbor and Sinclair Inlet.

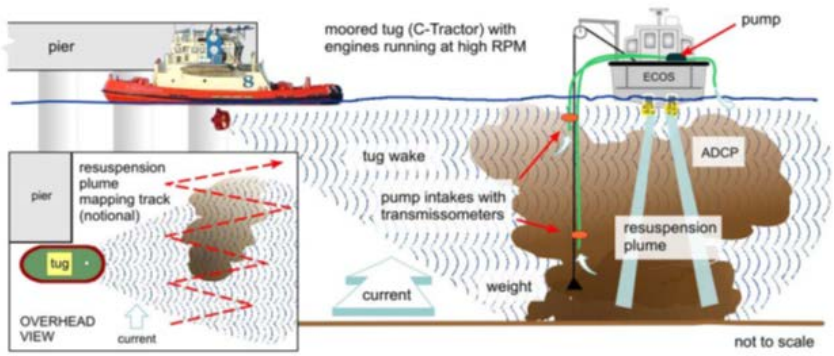

Figure 5-2. Diagram and Photo of a Resuspension Event Procedure Induced by a Tug.

Table 5-1. Number and Type of Analytical Samples for all Three Resuspension Studies.

Task	Matrix	Location	Number of Sites	Analytes	Fractions
Background levels	Water	Resuspension site mid-depth	3	Metal and organic CoCs	Total and dissolved
	Sediment	Resuspension site surface sediments	3	Metal and organic CoCs	Total, sand, silt, clay
Plume levels	Water	Plume surface	Site & event dependent	Metal and organic CoCs	Total, sand, silt, clay, dissolved
	Water	Plume mid-depth	Site & event dependent	Metal and organic CoCs	Total, sand, silt, clay, dissolved

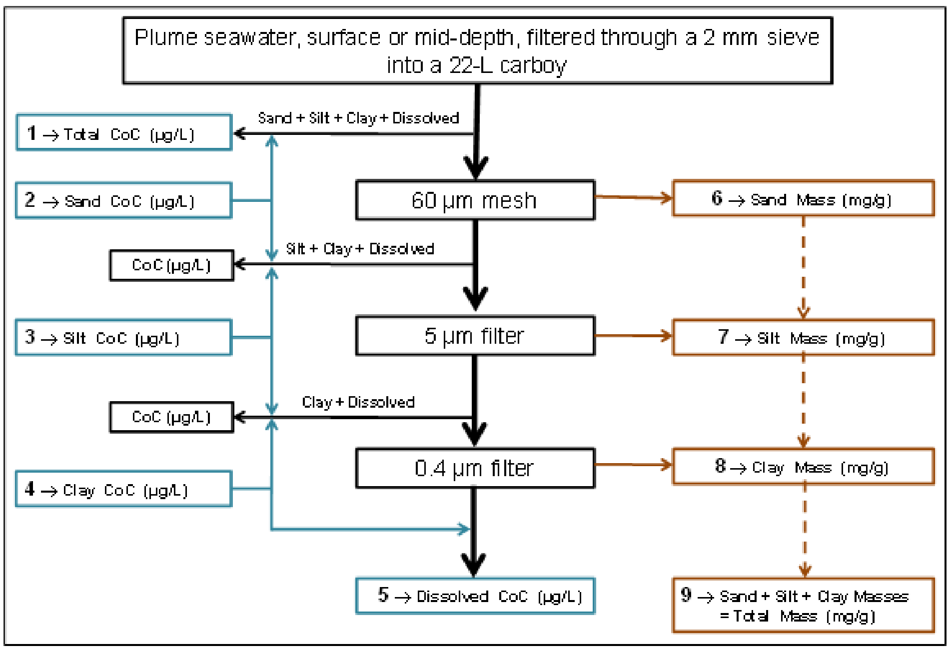

Figure 5-3. Flowchart of Laboratory Processing and Analysis of the Field Samples for Determination of CoC (i.e., Metals or Organic Contaminants) Concentrations in the Total, Sand, Silt, Clay and Dissolved Fractions.

5.3 DEEP-DRAFT RESUSPENSION STUDY IN PEARL HARBOR

Acoustic backscatter and derived suspended sediment concentrations (SSC) was measured by Engineer Research and Development Center (ERDC) personnel on 31 August 2012 off Bravo Pier in the wake of the USS Chafee, a DDG [length 155 m, beam 20 m, loaded draft 9 m (us.navy.mil)]. The vessel operations on the afternoon of 31 August (also from Bravo Pier) offered a contrasting case of plume generation. In this case the USS Chafee was pulled abeam from the Bravo Pier by two tugs. The tugs performed a turning maneuver in the basin and assisted the Chafee's departure from the berthing area. Incidental observation of SSC PAC was used to validate FANS predictions of sediment resuspension from a deep-draft vessel during tug assist.

5.4 SEDIMENT TRAP STUDY IN SINCLAIR INLET

Shore installations at PSNS & IMF, located in Sinclair Inlet, include seven piers and six dry docks where ship repair and salvaging occur. The sediment remediation cap lies near the head of Pier 7, partially underneath the pier and partially exposed between Piers 7 and 6 (Figure 5-4). Figure 5-4 shows the position of nine sediment traps and a picture of one of them, which were set to capture the sediment re-suspended during the events described in Table 5-2. At the end of the deployment time, the sediment traps were recovered, the sediment collected in them was sampled as completely as possible. The sediment samples were processed in the laboratory following a procedure similar to that shown in Figure 5-3.

Figure 5-4. Sediment Trap Locations under Pier 7, PSNS & IMF. The Stars Are Depicting the Label and Position of the Sediment Traps with Respect to Both Pier 7 and the Amendment Cap on the Sediment (Gray Area).

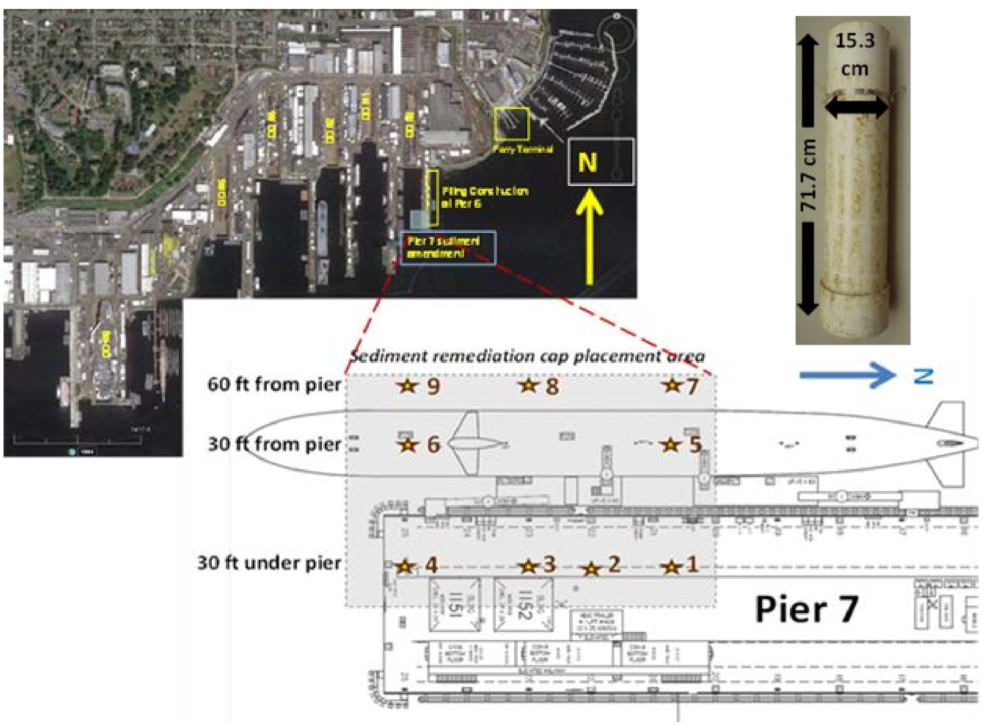

Table 5-2. Description of the Three Deployments Events for Quantification of Particle and Contaminants of Concern Deposited onto the Sediment Remedial Cap in PSNS & IMF Pier 7.

Sampling Event	Deployment dates (2014)	Deployment period (days)	Known deployment conditions
First (DD3)	22 January – 8 April	76	Two submarines undocked from Pier 7 and docked into Drydock 3(DD3)
Second (DD6)	10 April – 13 May	33	Carrier undocking from Drydock 6 (DD6) and transit out of Sinclair Inlet
Third (BCKGND)	14 May – 24 June	40	Background conditions (normal Sinclair Inlet traffic & ferry operations)

6.0 PERFORMANCE ASSESSMENT

In this section, field data and model results are compared to identify the performance of the models. These comparisons have the objectives to: (1) evaluate Maynord's model predicting resuspension in San Diego Bay via pump samples; (2) evaluate the CH3D+TICKET model predicting transport and partitioning in San Diego Bay via pump samples; (3) evaluate CH3D predicting transport in Pearl Harbor at Bravo and Oscar Piers via acoustic backscatter; (4) evaluate FANS predicting hull resuspension from the deep-draft USS Chafee via acoustic backscatter; and (5) evaluated CH3D predicting transport in Sinclair Inlet via sediment traps and recontamination of remediation site.

6.1 IMPLEMENTATION OF MAYNORD'S MODEL FOR SAN DIEGO BAY

In the field study, a Navy-contracted tugboat (Tractor C-14, Figure 6-1) was used to provide the propeller wash under controlled conditions. The tugboat with twin-nozzle propeller, was moored between Pier 4-5 with the bow pushing against the pier wall and the propellers thrusting toward the pier water. At 110 meters behind the tugboat, a PIV and an ADV were mounted to a frame which was placed on the bottom before the experiment started (Figure 6-1). The PIV measured the water velocity profile near the bottom (0-15 cm), and the ADV measured the water velocity at 15 cm above the bottom, during the study period of 13.847-14.44 hours (since 00:00AM 19 July 2012).

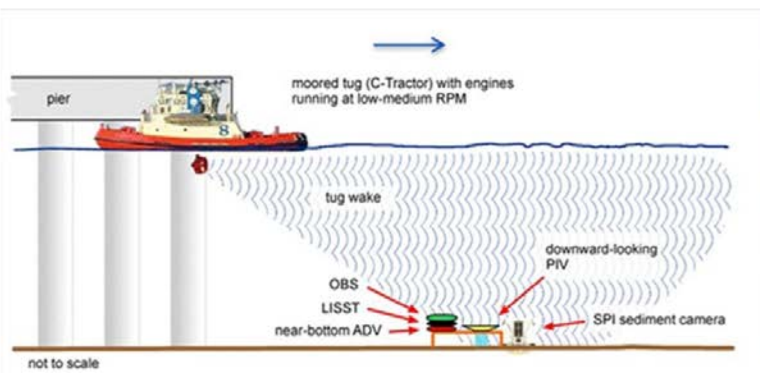

Figure 6-1. Field Study of Tugboat Propeller Wash at Pier 4-5 of Navy Base San Diego (Configuration of Instruments in Propeller Plume, Left, and Tugboat Tractor C-14 in Operation, Right).

Figure 6-2 shows combined images acquired at different times when the sediment bed was visible. From these images, it was observed that there was a continuous erosion of the bed before the propeller stopped at 14.41 hour. After that, the sediment bed actually rose up slightly, probably due to sediment deposition. It was estimated that the change of sea bottom was a function of time, as shown in Figure 6-2. Two parameters are needed to calculate erosion rate, the critical shear stress (τ_{cr}) and the empirical erosion constant, a. The critical shear stress was determined by visually checking PIV images for the initiation of sediment entrainment. The critical shear stress was estimated by calculating the mean velocity profile over a 5-second period, around the moment when the initiation of resuspension was observed.

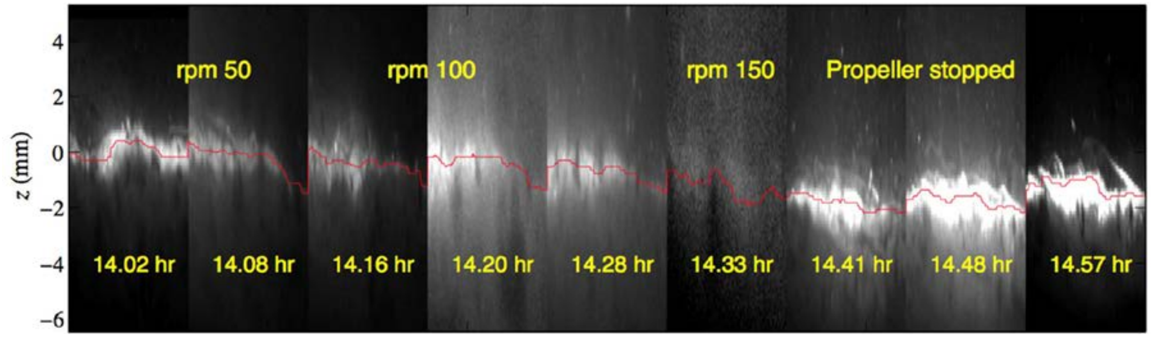

Figure 6-2. PIV Images with Visible Sediment Bed.

The red line is the reconstructed bottom line from the bottom image.

The bottom shear stresses estimated from these three energy-balanced methods were compared with the shear stress calculated by the Maynord's model. Figure 6-3 shows the cumulative bottom shear stress over time. Cumulative shear stress provides overall effects of the shear stress including the mean and temporal variations over time. Figure 6-3 also shows predicted total sediment erosion mass during the four propeller speeds. The erosion rate starts from 0.007 kilogram-meter per second (kg/m^2/sec) for the 20 Revolutions per minute (RPM), to 0.44, 10.96, and 32.87 kg/m^2/sec for the 50, 100, and 150 RPM. Therefore, major resuspension occurred during the periods of 100 RPM (5918 kg) and 150 rpm (15,383 kg). At the end of the propeller running period, a total of 21571 kg of sediment mass was predicted to be eroded into the water column.

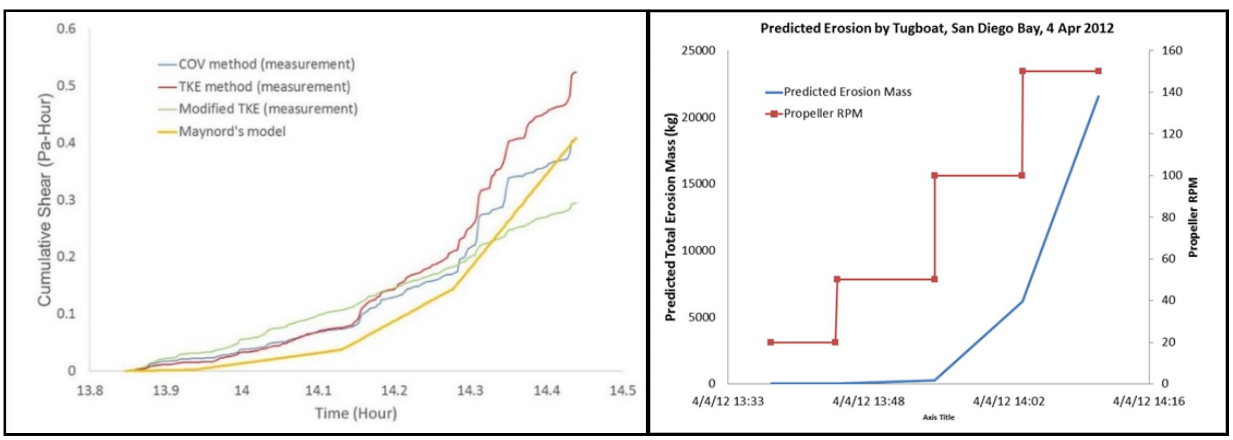

Figure 6-3. Left Panel: Cumulative Shear Stress over Time between Model Results and Estimation Based on Measured Velocity Field during the Propeller Wash Experiment, Right: Model Predicted Total Eroded Sediment Mass during the 33-minute Period.

6.2 CH3D+TICKET FOR TRANSPORT AND PARTITIONING IN SAN DIEGO BAY

Simulations with the linked CH3D+TICKET model were conducted for the period of 4/2/0:00 to 4/12/0:00 in 2012 for a total of 10 days. Resuspension event occurred during 4/4/13:55-14:25, which was about 62 hours after the hydrodynamic model started, a time period long enough to eliminate any numerical noise due to the cold start of the model simulation.

Figure 6-4 shows the snapshots of simulated and measured water-column concentrations of clay, silt and sand during the 1-hour period of field data sampling after the propeller resuspension (14:15 -15:06, 4/4/2012). Both simulated and measured concentrations of clay, silt, and sand particles are within the same range (0-10 mg/L). Figure 6-4 also shows the deposition of clay, silt, sand and total sediment at the end of 7.5 days from the resuspension. Simulated dissolved and total copper concentrations were compared with measured values. Figure 6-5 shows the snapshot contours of simulated total deposited solids and deposited copper. Figure 6-6 shows the time series model results and the field data for copper bounded with clay, silt and sand particles. Similar to those of the sediment results, simulated dissolved and total copper concentrations are in agreement with the measured values.

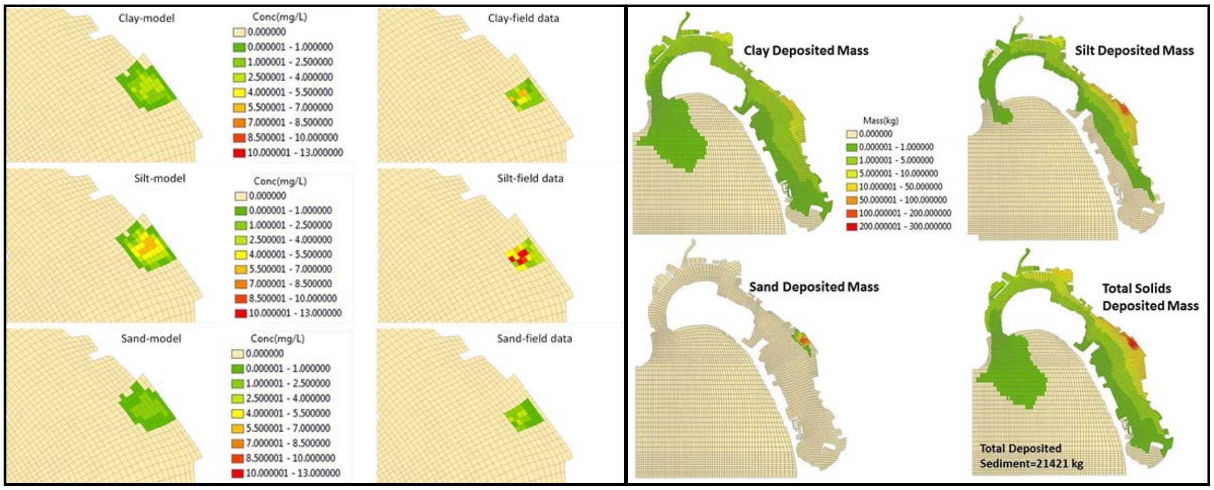

Figure 6-4. Left Panel: Snapshots of Water Column Concentrations of Clay (top), Silt (Middle) and Sand (Bottom) between Model (Left) and Field Data (Right), Right Panel: Simulated Deposition Mass of Clay, Silt, Sand and Total Sediment Particles from the Propeller.

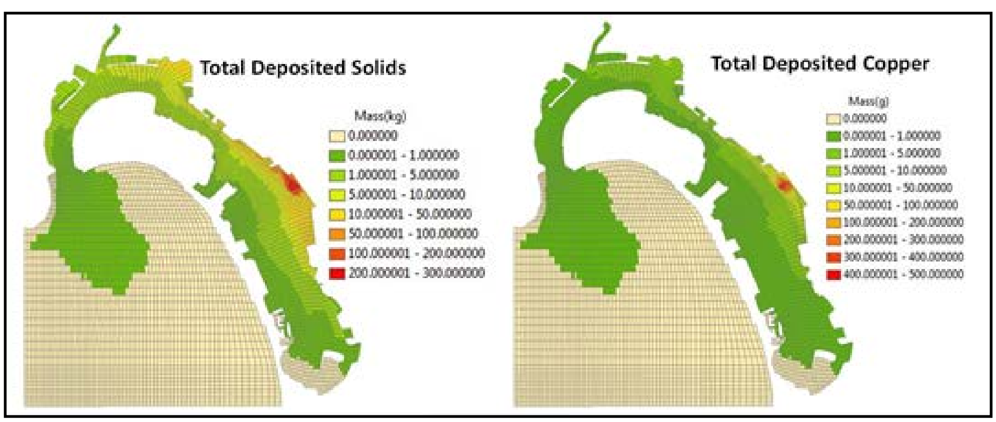

Figure 6-5. Comparison between Total Deposited Solids and Total Deposited Copper.

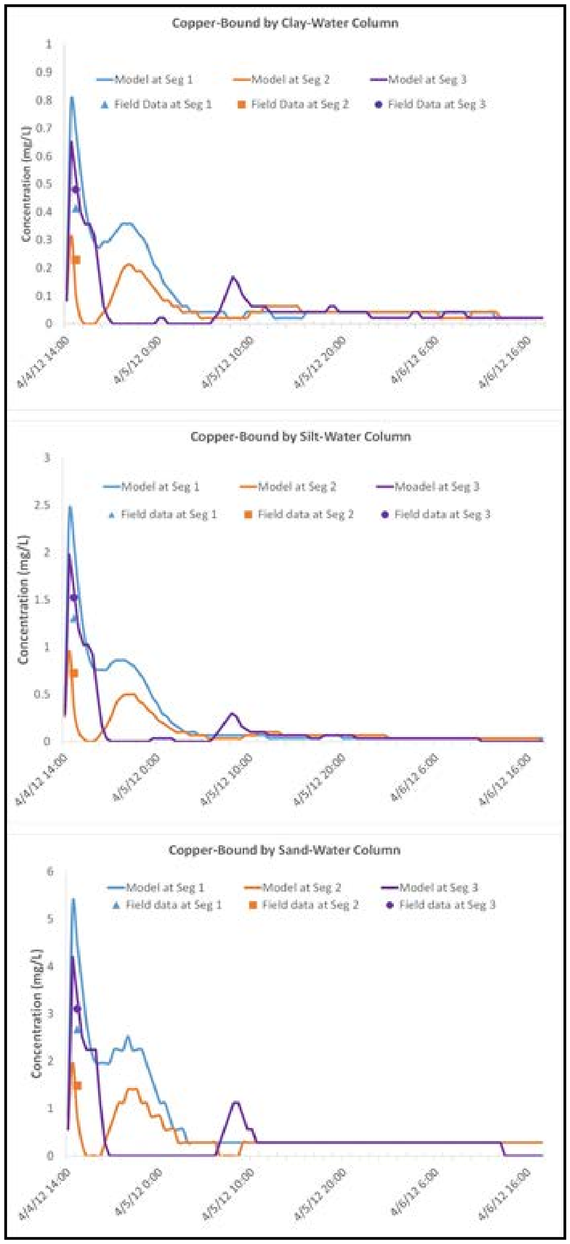

Figure 6-6. Model/Data Comparison of Copper Concentrations Bound by Clay (top), Silt (Middle) and Sand (Bottom) Particles, Respectively for the Three Locations.

For this study, a total of 21,571 kg sediment mass, predicted by the Maynord's model, was introduced into the CH3D model to simulate subsequent fate and transport of the plume. Within the 74-minute window when field data was measured, model-simulated water column concentrations of clay, silt, sand, and TSS were compared with the measured data with good agreement between the two. Such good agreement is significant because it validates the Maynord's model prediction of the 21,571 kg of sediment eroded by the tugboat. This is the first direct validation that we know of, for the total eroded sediment mass by a tugboat using a validated model and field data. The model/data agreement also validates the CH3D model for the three particles, clay, silt, and sand and the TSS.

6.3 CH3D PREDICTING TRANSPORT IN PEARL HARBOR

For the Pearl Harbor study, the calibrations of SSC, based on acoustic backscatter, were applied to the corresponding datasets to produce a space-time mapping of backscatter-estimated *SSC*. An example period of *SSC* data estimated from the ADCP backscatter is provided in Figure 6-7. The data are from the 28 Aug tug experiment at Bravo Pier, and the vertical profiles displayed in the lower panel correspond to 20 to 25 minutes after the second tug pulse generating a suspended sediment plume. The solid white line in the lower panel indicates the bed position relative to the transducer and the colored track lines in the upper right panel of Figure 6-7 show the relative position of the vessel corresponding to the profile data in the lower panel. The red marker indicates the approximate position of the tug that generated the suspended sediment plume.

For the Pearl Harbor study, the measured size-specific TSS and copper concentrations associated with sediment, and in the dissolved state at Bravo Pier and Oscar Pier were interpolated and assigned to the model grid as the initial conditions for the model. Model simulation continued for 60 hours before the initial copper concentrations were assigned for the Bravo Pier at 12:00, 28 August, and for 84 hours before the initial copper concentrations were assigned for the Oscar Pier at 12:00, 29 August. Simulation continued until 23:00, 2 September 2012. Model output of dissolved and silt-bound concentrations in the water column and silt-bound deposits to the sediment bed were analyzed.

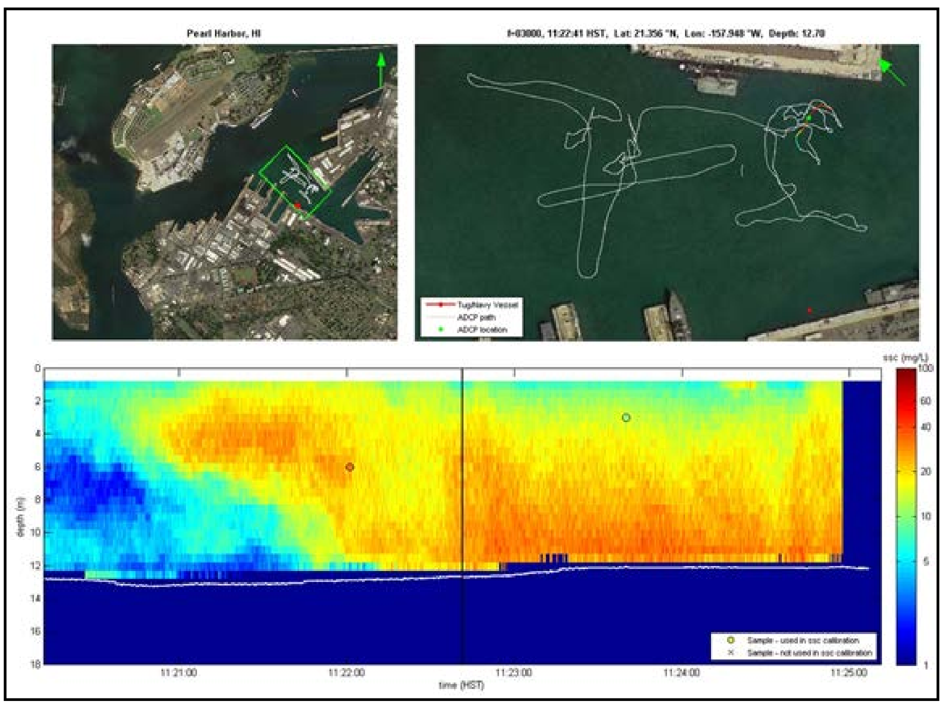

Figure 6-7. Space-time Mapping of Suspended Sediment during the 28 Aug Tug-generated Plume.

Aerial photo from Google. Site Map (upper left), expanded site map with track line of the ADCP measurements (upper right). The lower plot is for vertical profiles of acoustic estimates of SSC.

6.3.1 Bravo Pier

Figure 6-8 shows the simulated transport patterns of dissolved copper in the surface layer at six selected times, t = 0 (initial condition), 3, 9, 18, 30, and 120 hours after the propeller wash. The propeller wash took place at the end of a flooding tide, and fate and transport was initiated during the ebbing tide. During the first 3 hours, ebbing tides transport the plume out of the naval station channel going first westward and then northward. As time progresses, the plume starts to go through tidal dispersion processes, oscillating during tidal cycles with the plume expanding to other regions. Dilution and expansion of the plume can be visualized from these figures. At the end of 5th day, the dissolved copper concentrations are diluted from an initial concentration of ~ 12 to ~ 0 to 0.2 µg/L values, a reduction of 98.5% in concentrations, whereas the domain of the plume expanding to almost entire harbor.

Silt-particle-bound copper is subject to settling, which removes silt-bound copper from the water column to the bottom sediment bed. Figure 6-8 also shows simulated silt-particle-bound copper concentrations at the surface layer and the bottom layer at the times of t=0 (initial condition), 3, 9, and 18 hours. At 9 hours, simulated silt-bound copper concentrations reduce to a 0.0- to 0.2-µg/L level, whereas dissolved copper retains a highest concentration ~ 10 µg/L. At 18 hours, silt-bound copper concentrations reduce to zero in the surface layer.

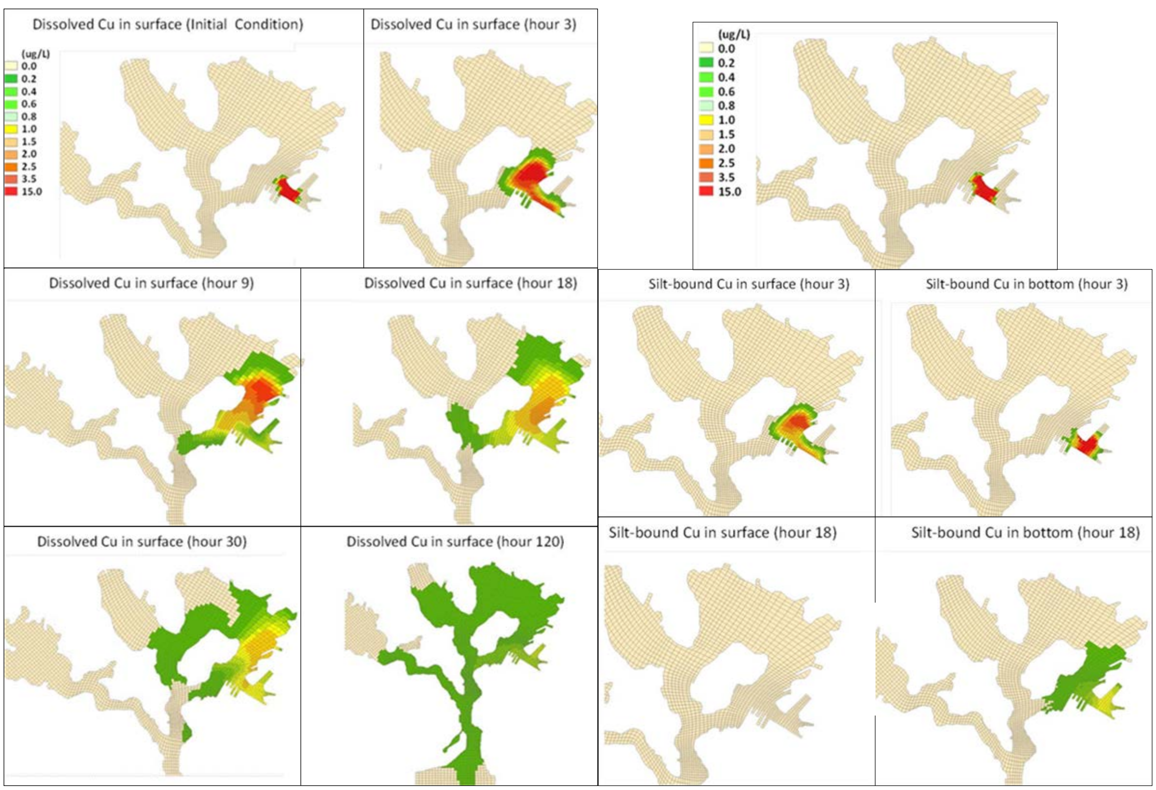

Figure 6-8. Left panel: Simulated Dissolved Copper Concentrations at Surface Layer at Different Times after Prop-wash Resuspension at Bravo Pier, Right Panel: Simulated Silt-particle-bound Copper Concentrations at Initial Condition (Top), Surface (Left) and Bottom Layer (Right) 3 Hours (Center) and 18 Hours (Bottom) after Prop-wash Resuspension in Bravo Pier.

6.4 RESUSPENSION FROM A DEEP-DRAFT VESSEL

6.4.1 Field Observations Using ADCP

The vessel operations on the afternoon of 31 August 2012 (also from Bravo Pier) offer a contrasting case of plume generation, relative to the plumes generated by the tugs at Bravo and Oscar Piers. In this case (Figure 6-9), the USS Chafee [length 155 meter (m), beam 20 m, loaded draft 9 m[1]] was pulled abeam from the pier by two tugs. The tugs performed a turning maneuver in the basin and assisted the Chafee's departure from the berthing area. A large, turbid surface plume was observed during the turning maneuver. Approximately 13 minutes after the vessel operation commenced, the ADCP survey began and measured *SSC* values on the order of 80 mg/L with a longitudinal scale of approximately 500 m (several times the length of the Chafee). The subsurface plume extended well into the turning basin and persisted with concentrations on the order of 20-30 mg/L at 1 hour and 10-15 mg/L at approximately 3 hours. These observed plume patterns are consistent with the FANS model results for the deep-drafted vessel, i.e., DDG, to be discussed in Section 6.4.2 immediately below.

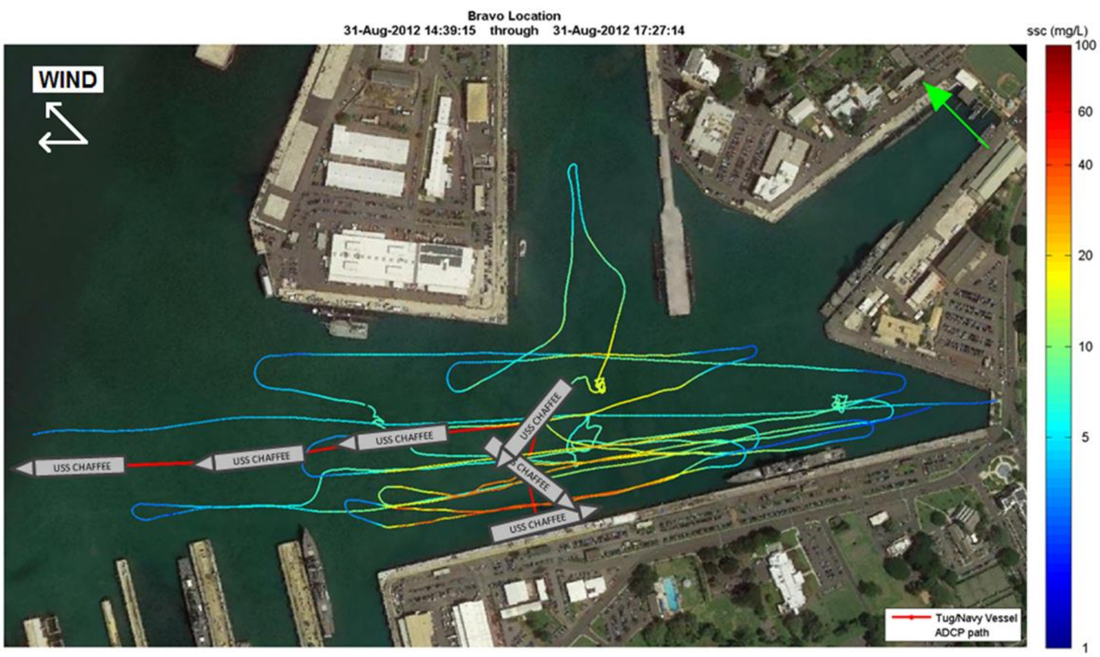

Figure 6-9. ADCP Track Line with Depth-averaged SSC (31 Aug 2012) Indicated by Color. Note that the Track Positions Vary with Time and Do Not Indicate a Snapshot in Time.

The sketched vessel positions indicate the approximate positions and sequence of vessel maneuvers during plume generation. Aerial photo: Google.

6.4.2 Simulation Scenarios for DDG-51 Ship

FANS simulation were performed for a DDG-51 ship as shown in Figure 6-10 under two different water depths (10.0588 m and 11.5824 m) and two different propeller rotating speeds (26 and 51 RPM).

[1] The US Navy -- Fact File: Destroyers - DDG, http://www.navy.mil/navydata/fact_display.asp?cid=4200&tid=900&ct=4, accessed 13 Jan 2016.

The diameter of the twin-screw propellers is 5.4864 m (18 ft), and the center of propeller axis is located at 5.7912 m below the mean water level. For the shallow water case with 10.0584 m (33 ft) water depth, the under keel clearance is only 0.6096 m (2 ft) beneath the sonar dome and the minimum gap between the propeller tip and the sea bottom is 1.524 m (5 ft). The propeller rotating speed is 26 rpm when the ship speed is 5 knots.

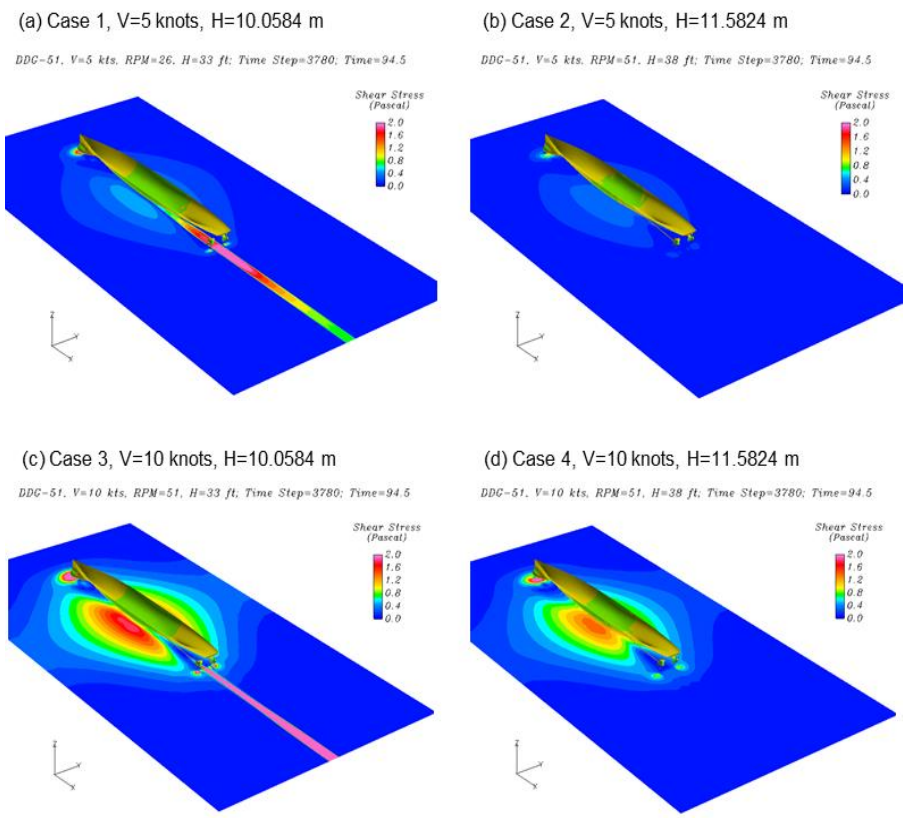

Figure 6-10. Simulated Bottom Shear Stress by FANS3D.

6.5 SEDIMENT RECONTAMINATION POTENTIAL FOR PIER 7, SINCLAIR INLET, WA

The sediment traps were sampled at the end of three time periods: (1) 22 Jan to 8 Apr 2014, when two submarines were undocked from Pier 7 and led into DD3, (2) 10 Apr to 13 May 2014, when a carrier from DD6 transited out of Sinclair Inlet, and (3) 14 May to 24 June 2014, when background conditions were presumably measured.

The silt (60 to 5 µm) particle size fraction is the major component of the load settled onto the sediment remedial cap under Pier 7, PSNS & IMF. This is similar to the resuspension events in San Diego Bay and Pearl Harbor, where the silt fraction also was the major component in sediment re-suspended under controlled conditions. In order to evaluate and provide further insight to the sediment/metal data collected from the sediment traps, we attempted to use CH3D for some baseline modeling and evaluate the model results with the measured data. In order to make our analysis meaningful, the same sediment erosion mass (i.e., 21,571 kg), which was predicted for San Diego Bay using the Maynord's model, was assumed and used as eroded sediments from DD3 and 6, respectively.

Figure 6-11 shows the model simulated total deposition rates (g/m^2) for silt, sand particles and TSS from the initial re-suspended sediment at DD3. Overall, the primary deposition zones center around DD3 with values reaching over 100 g/m^2. Deposition rate at Pier 7 are 25.2 (g/m^2) for silt and 20.3 (g/m^2) for sand particles. The major deposition from drydocking a carrier in DD6, centers around the dry dock region with highest deposition rate ~100 g/m^2 (not shown). Deposition extends along the pier walls, but decays fast with the deposition rates of ~0.6 g/m^2 and 2.7 g/m^2 for silt and sand, respectively at Pier 7. These deposition rates are one order of magnitude <the daily deposition rate from the data, which ranges between an average of 20 g/m^2/day, and 30 g/m^2/day for silt and sand, respectively. It should be noted about the different units between the model (g/m^2 for the event) and the field data (g/m^2/day).

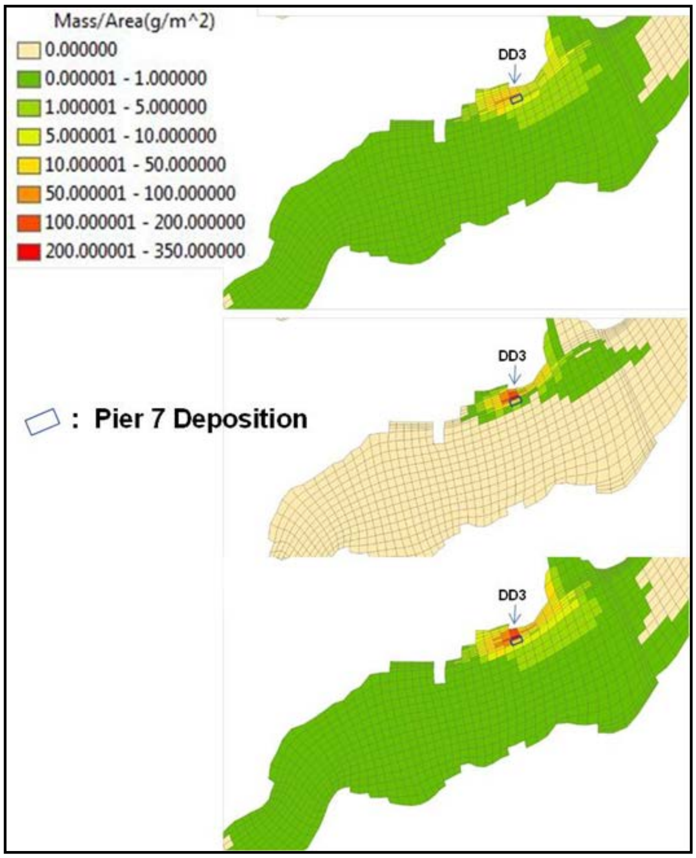

Figure 6-11. Deposition Rates for Silt (Top), Sand (Middle) and TSS (Bottom) from Sediment Plumes in Drydock #3.

Table 6-1 shows comparison of averaged deposition rates at Pier 7 between the DD3 and 6 resuspension events. Simulated deposition rates from DD3 event were close between silt (20.3 g/m2) and sand (25.2 g/m^2), comparable to the measured data of 9.5 (g/m^2-day) for silt and 40.8 (g/m^2-day) for sand. Simulated deposition from DD6 event is only about 2% of that from DD3 event for silt, and 13% for sand particles. As shown in Figure 6-11, the plumes from those two events got dispersed over distance from the resuspension sites.

Table 6-1. Integrated Deposition Rate at Pier 7: Model Results (g/m²) and Field Data (g/m²-day).

Deposition Rate	Event 1		Event 2		Event 3
	Model (g/m²)	Data (g/m²-day)	Model (g/m²)	Data (g/m²-day)	Data (g/m²-day)
Sand	20.3	40.8	2.7	34.7	29.8
Silt	25.2	9.5	0.6	27.6	19.4
Clay	~0	~0	~0	~0	~0

A comparison between the metal concentrations (µg/g) in the particles collected by the sediment traps and those in the background sediment provides evidence of the provenance of the particles. Figure 6-12 is the plot of the average metal concentration measured in each of the three events versus the average metal concentration in the background sediments collected by and in between the piers in PSNS & IMF.

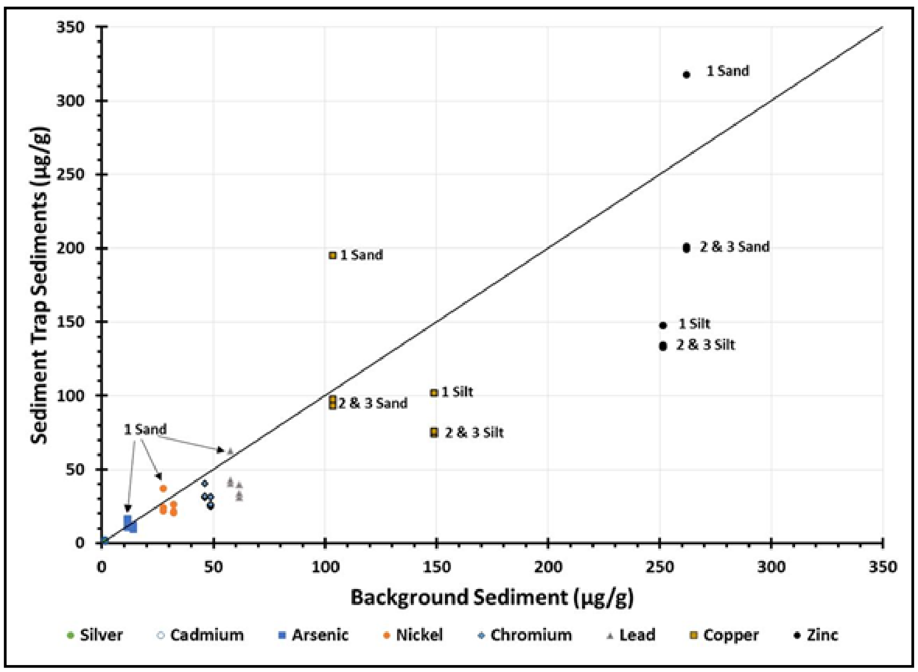

Figure 6-12. Mean Sediment Trap Particle Concentration (µg/g) versus Mean Background Sediment Concentration (µg/g). Data are Presented for each Metal in the Sand and Silt Fractions and for Each of the Three Events.

There is a deviation to the positive side of the 1:1 relationship for copper and zinc in the sand fraction of Event 1 (DD3). Copper concentration in the sand-size particles in average are about twice the concentration in background sediment, while the difference in zinc is about 1.2. In general, most of the other metals also show a larger concentration in the particles for the sand fraction in Event 1 (DD3). This indicates that the particles originated, at least in part, from a different source, with larger concentration of these and the other metals. The most plausible source is sediment closer to DD3. The shuttling of the two submarines, previously docked in Pier 7, to DD resulted in resuspension of larger particles (sand) in the area closer to the drydock. The re-suspended sand had relatively high levels of copper and zinc relative to background (Figure 6-12). This may be due to the opening and closing of the caisson, combined with the effect of tug boats pushing the submarines into position for docking, as well as the dewatering of the drydock.

The last result also indicates that the source of the silt fraction is from a larger area or a longer deposition time. The dissimilarity between the sand and silt fractions for copper and zinc in the first event indicates that sand should come from a closer source with higher metal concentration (sediments by the caisson as discussed above). In contrast, the silt fraction for event 1 is not as different to the silt concentrations in Events 2 and 3, indicating that the source of the silt fraction is more similar, or that the proportion between the silt generated and deposited in event 1 has a stronger effect from silt re-suspended in other areas of the inlet (i.e., ferry and vessel transit, other anthropogenic or natural phenomena resulting in resuspension of sediment) than the sand fraction. This is evidence that the particles collected in the sediment traps under Pier 7 are affected by processes occurring beyond piers of PSNS & IMF.

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7.0 COST ASSESSMENT

Prediction of the fate of contaminant load associated with particles re-suspended by propeller wash must include the setting up, calibration, validation and application of the two main models developed in this effort, the Graphic Maynord's Model and the CH3D+TICKET Model. Calibration could be accomplished by having a single resuspension event, similar to those accomplished in San Diego Bay and Pearl Harbor as part of this project.

7.1 COST MODEL

As the approach for development, calibration and validation of the models followed in this project was similar for the three DoD harbors, the cost model presented here is for the effort in San Diego Bay. Table 7-1 shows the costs incurred in the development, calibration and application of the models in San Diego Bay, and it is divided in different cost elements for each of the separate tasks required for application of the models. These costs elements are described below.

Instrument rental/purchase and calibration in laboratory. These costs are associated with rental fees, purchasing, calibration and preparation of the suite of instruments required for resuspension field measurements. These instruments include ADV, ADCP(s), PIV shear detector, SPI camera system, pumps and hoses for sampling of re-suspended sediment, carboys/containers for sample, etc. In the case of San Diego Bay, some of these instruments required purchasing.

Resuspension event and background sediment sampling. These illustrate the operational costs for taking three cores of background sediments prior to the resuspension event, having a tug boat tied to a pier and cranking up the propeller to different speeds for determination of the shear speed that re-suspends the sediment, collecting ten samples from the plume of re-suspended sediment, and collecting data associated with the currents generated by the tug boat during the resuspension. This process was followed in the resuspension events performed in San Diego Bay and Pearl Harbor as part of this project.

Laboratory preparation and analysis. This describes the labor costs for separation of the background sediments and re-suspended sediment samples into the four grain-size classes investigated in this project as shown in Figure 5-3, and the costs associated for quantification of organic and metals CoCs in these fractions.

Graphic Maynord's Model. These are the costs expected from setting up the Graphic Maynord's Model to the body of water, as well as calibration, validation and application of the model.

CH3D+TICKET Model. Similar to above, these are the costs expected for setting up, calibration, validation and application of the CH3D+TICKET Model to the body of water.

Report. These costs are expected for analysis and explanation of results from the two models, and prediction of fate of CoCs after resuspension in the body of water.

The estimates presented here do not include some costs. These include costs for traveling back and forth to the body of water from the organization place. Shipping costs of instrumentation or samples are not included, as well as administrative costs. As the two models were developed as part of this ESTCP-funded effort, costs for development of the models are not included for future endeavors.

Table 7-1. Costs Model from the Modeling Development in San Diego Bay.

Cost Element	Data Tracked During the Demonstration	Costs		
		Description	Qty	Units
Instruments rental/purchase and laboratory calibration	• Personnel and labor	Lab technician		hours
		Certified Engineer		hours
	• Equipment	ADV		rental
		ADCP		purchase
		PIV shear detector		purchase
		SPI camera system		rental
	• Materials	Filters, etc.		cost
Resuspension event and background sediment sampling	• Personnel and labor	Captain		hours
		Sampling boat driver		hours
		2 ADCP operators		hours
		3 Sampling technicians		hours
	• Equipment	Boats rental		rental
		Tug boat rental		hours
		Tug boat fuel		cost
	• Materials	Sampling equipment		cost
Laboratory preparation and analysis	• Personnel and labor	Lab technician		hours
	• Analytical costs	Materials		cost
		Organics		cost
		Metals		cost
Graphics Maynord's Model	• Personnel and labor	Modeler		hours
		Computer technician		hours
CH3D+TICKET Model	• Personnel and labor	Modeler		hours
		Computer technician		hours
Report	• Personnel and labor	Modeler		hours

Qty is quantity.
Cost was used to identify a group of materials and/or fuel consumption by the tug boat as a lump sum.

7.2 COST DRIVERS

Management of contaminated sediments is the main driver for implementing prop wash resuspension modeling in DoD harbors. Modeling of sediment resuspension by propeller wash is applicable to bodies of water with strong evidence or confirmed presence of contaminated sediments. This modeling is pertinent to the management and remediation of these contaminated sediments, and should indicate the most efficient, cost effective, and long-term management approaches in that specific body of water. Most probably the application of this modeling is response to regulatory scrutiny, and desire for improving public opinion.

7.3 COST ANALYSIS

The cost model presented here is for sampling and quantification of required data, and costs associated with setting up, calibration, application and description of the modeling results to a different DoD Harbor. Assumptions for this scenario include the case in a body of water where environmental information required for modeling (i.e., currents' speed and direction, bathymetry, tidal information, etc.) is available. There is a requirement of assessing background sediments with respect to particle size distribution and associated metal mass loading, which will be accomplished by sampling, manipulation (i.e., grain size separation in four classes) and analysis of three sediment cores. There also is a requirement for the highest confidence in the results from the modeling, which will be accomplished by calibration with data from one resuspension event. Table 7-2 shows the costs expected for this scenario.

This cost scenario does not include any comparison, as we are not aware of any other available modeling of prop wash resuspension. Cost savings, and improvements on environmental condition and public opinion are difficult to evaluate.

Table 7-2. Costs Expected for the Scenario of an Embayment where Basic Hydrologic Information is Available, and there is a Requirement for High Resolution in the Predicted Fate and Transport of Particles Re-suspended by Propeller Wash.

Cost Element	Data Tracked During the Demonstration	Costs				
		Description	Qty	Units	Price/ unit	Price/ item
Instruments rental/purchase and laboratory calibration	• Personnel and labor	Lab technician	80	hours	$118	$9,418
		Certified Engineer	24	hours	$118	$2,825
	• Equipment	ADV	1	rental	$5,000	$5,000
		ADCP	2	purchase	$20,000	$40,000
		PIV shear detector	1	purchase	$5,000	$5,000
		SPI camera system	1	rental	$5,000	$5,000
	• Materials	Filters, etc.	1	cost	$2,000	$2,000
					SubTotal	**$69,243**

Table 7.2: Costs Expected for the Scenario of an Embayment where Basic Hydrologic Information is Available, and there is a Requirement for High Resolution in the Predicted Fate and Transport of Particles Re-suspended by Propeller Wash. (Continued)

Cost Element	Data Tracked During the Demonstration	Costs				
		Description	Qty	Units	Price/ unit	Price/ item
Resuspension event and background sediment sampling	• Personnel and labor	Captain	8	hours	$118	$942
		Sampling boat driver	8	hours	$118	$942
		2 ADCP operators	16	hours	$118	$1,884
		3 Sampling technicians	24	hours	$118	$2,825
	• Equipment	Boats rental	2	rental	$2,500	$5,000
		Tug boat rental	8	hours	$1,200	$9,600
		Tug boat fuel	1	cost	$3,000	$3,000
	• Materials	Sampling equipment	1	cost	$5,000	$5,000
					SubTotal	**$29,192**
Laboratory preparation and analysis	• Personnel and labor	Lab technician	480	hours	$118	$56,506
	• Analytical costs	Materials	1	cost	$3,000	$3,000
		Organics	1	cost	$30,000	$30,000
		Metals	1	cost	$10,000	$10,000
					SubTotal	**$99,506**
Graphics Maynord's Model	• Personnel and labor	Modeler	200	hours	$118	$23,544
		Computer technician	320	hours	$118	$37,670
					SubTotal	**$61,214**
CH3D+TICKET Model	• Personnel and labor	Modeler	320	hours	$118	$37,670
		Computer technician	560	hours	$118	$65,923
					SubTotal	**$103,594**
Report	• Personnel and labor	Modeler	480	hours	$118	$56,506
					SubTotal	**$56,506**
					GRAND TOTAL	**$419,254**

Cost was used to identify a group of materials and fuel consumption by the tug boat.

8.0 IMPLEMENTATION ISSUES

In this study, we have collected important and essential field data also developed tools (models) for prediction and evaluation of the impacts. Use of these methods will lead to more informed evaluation of remedial options and to improve the predictive capabilities for potential recontamination of sediment remedial sites. Lessons learned during the demonstration study are provided below.

- Collection of field data of propeller wash is challenging due to the highly turbulent flow dynamic boat, and propeller movements during the study
- Good coordination and cooperation with the boat crew, in particular, the driver of the boat is important so that the tug wash experiment can be conducted under controlled conditions.
- Good logistical support and coordination are needed for field study
- Field data are important and costly and collection and analysis are laborious. It is necessary to plan well and identify the types of data based on priorities and budget.
- Models can be effective, if calibrated and validated against field data
- Models need to be more user-friendly so that they can be used by people other than the developer(s) of the models. This can be effectively achieved in two ways:
  - Make graphic user interfaces for easy model input and model output
  - Provide users' manuals for the models
- Further research is needed for long term impacts with and without propeller wash on sediment dynamics and remediation options in DoD harbors
- Maynord's model is based on the theory of conservation of momentum and implemented for propellers with a single engine (Maynord 1984) and twin propellers (Maynord 2000). While convenient, Maynord's model has its application limitation – namely, the ratio of propeller diameter to propeller-to-bottom distance, Dp/Hp, should be < 1.2. Specifically, Maynord's model is applicable for propeller wash studies for tugboats and may not be applicable for deep-draft vessels, such as aircraft carriers and DDGs.

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Ken Richter	SSC Pac 53475 Strothe Rd., San Diego, CA 92152	(619) 553-2780 richter@spawar.navy.mil	Field work, design of frames for ADCP and other instruments
Qian Liao	Dept of Civil Engin. & Mechs. U of Wisconsin Milwaukee, WI 53201	(414) 229-4228 liao@uwm.edu	PIV, ADV for tug wakes/plumes, empirical bottom shear stress and erosion rate
Kevin Farley	Manhattan College Dept of Civil & Environ. Eng. Riverdale, NY 10471	(718) 862-7383 kevin.farley@manhattan.edu	Developed look-up table for copper partitioning in San Diego Bay for linkage CH3D+TICKET
Hamn-Chin Chen	Dept. of Civil Engineering Texas A&M U. 3136 College Station, TX 77843-3136	(979) 847-9468 hcchen@civil.tamu.edu	Implemented FANS model for resuspension
Joe Germano	Germano & Associates 12100 SE 46th Pl, Bellevue, WA 98006	(425) 865-0199 joe@remots.com	SPI instrument deployment and image processing
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